IRAT
Institut de Recherches Agronomiques Tropicales
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Département du Centre de Coopération Internationale
en Recherche Agronomique pour le Développement (CIRAD)

REPORT ON A MISSION TO THE YEMEN FOR BAFY

from 07 to 15 december 1991

by P. QUIDEAU, Agronomist, Hydraulic Engineer, CIRAD-IRAT

on

SUPPLEMENTAL IRRIGATION FOR HILL COFFEE PLANTATIONS

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1 - FRAMEWORK OF THE MISSION

1.1. Purpose

The purpose of the mission was to provide technical support for the *Bureau Agricole Franco-Yemenite* (BAFY) in drought control in hill coffee growing. The operation is entitled "Model of runoff management for the supplemental irrigation of Arabian coffee in the Yemen". In the present phase, it aims at testing the advantages and feasibility of water storage in cisterns and is sited on a slope of Jebel Beni Ismail not far from Manakhah.

During a previous mission from 15 to 19 October 1991, we examined the main features of the operation and discussed a trial procedure to demonstrate the effectiveness of supplemental irrigation. The main agronomic questions which arise were discussed during the December mission.

1.2 Persons met

The Interim Director of the Highland Agricultural Project Development (CHAPD).
The Cultural Adviser, French Embassy, Sana'a
Mr Abdul Halim, BAFY counterpart agricultural expert
Mr Olivier Neuvy, BAFY agricultural expert

1.3 Schedule

06 and 16 December 1991: Flight Paris-Sana'a and return
10, 11 and 14 December 1991: work at the Beni Ismail site
Other days: work in the office in Sana'a.

10 soil samples and 10 coffee samples were taken to the CIRAD laboratories in Montpellier.

II - GENERAL DESCRIPTION OF THE WORK CARRIED OUT

2.1. Demonstration of the effectiveness of supplemental irrigation of coffee-trees: Beni Ismail trial

This mission was devoted mainly to work with Mr Neuvy on gaining better knowledge of the hydric functioning of coffee-trees cultivated on hill terraces. The following approaches were used:
- analysis of measurements already made in 1991 at the Beni Ismail site,
- site observations made during the mission (watering test, root profiles, state of vegetation),
- water balance simulations,
- bibliography, with the help of Mrs Neuvy.

The main features examined are listed below and described in more detail in Chapter III.

. Meteorological records
. Precipitations other than rainfall
. Rooting
. Water characteristics of the soil
. Drought resistance
. Flowering and fruiting in relation to the rainfall regime
. The water balance and water requirements.

In parallel, the procedure of the Beni Ismail supplemental irrigation trial to be carried out in 1992 was detailed and completed (Chapter IV). A number of suggestions made after our previous mission were implemented.

We consider that the many measurements and observations which will be made as part of the experiment will considerably increase knowledge (very inaccurate today) of the climatic constraints of this region (Western Mountains), narrow terrace cultivation in general and the behaviour of coffee in particular. Analysis of these data will require a large amount of fairly complex work; BAFY would like to have support for this in 1992.

However, the experimental work is not the final aim but part of a broader operation of aid for coffee-growing initiated by BAFY and mentioned in 2.2 below. It is to provide the scientific data lacking to date to specify:
. the best procedures (depths, dates) for supplemental irrigation and how to best use water in the cisterns,
. the benefit which can be given by supplemental irrigation in terms of coffee quantity and quality.

2.2 Management of run-off water for supplemental irrigation of coffee-trees

Traditional irrigation is performed at the time of rainfall by diverting runoff from upstream zones. The soil is fully re-wetted several times a year (6 or 7 times in a normal year). No irrigation is therefore possible without rainfall able to cause runoff.

Stored water is necessary for watering without rainfall; cisterns are the only possible solution in these mountains. The technique is already used by some planters and new cisterns have been constructed in recent years to handle the increasingly severe drought. However, these cement tanks are expensive and mainly used for Arabian tea which is a more profitable crop than coffee. This year (severe drought), Arabian tea growers are bringing water from the mountains in tankers, a watering technique which is doubtless extremely expensive.

The BAFY scheme is thus to test small cisterns (several m^3) dug in the ground and made impermeable by plastic sheeting; this would make it possible to carry out supplemental watering at the foot of the coffee-trees (using a flexible hose). Several tens of tanks are to be constructed in 1992 using this technique; some will be at the Beni Ismail experimental site and others will be installed near coffee plantations by other farmers in the region.

Although overall surface flow is fairly limited in the zone (4 to 8% of total annual rainfall according to hydrological studies in Wadi Surdud from 1984 to 1988), there can be considerable local runoff. The farmers themselves are obviously best qualified to choose the best sites for the cisterns.

The construction technique is simple (a hole is dug with stable sides, flexible plastic sheeting is laid and a filling channel constructed). Field experience will show the best way to prevent perforation of the plastic and excessive silting at each filling (small settling basin, pebble filter, limiting the flow diverted to the reservoir).

III - AGRONOMY

3.1 Meteorological measurements at Beni Ismail

Temperature was over-estimated (3 °C) because of poor setting of the conversion formula for the sensor readings and the PEPISTA-INRA automatic apparatus. The sensor is protected from direct sunlight but not from radiation reflected by the ground and the wall of the neighbouring terrace; we therefore recommend that the shelter should be improved.

It would be interesting to compare the temperatures recorded at this site with those measured at similar altitudes deeper within the country or in East African coffee-growing regions. These temperatures seem fairly high in spite of the altitude, affecting water requirements and fruit formation rate. It might be explained by rising hot air from the Tihama valley, the south-facing orientation of the main slope (whereas the site faces east) and heat accumulation by the rock and the walls.

3.2 Non-rainfall precipitation

Distinction can be made between three phenomena:

- Condensation of atmospheric water vapour in contact with cold surfaces (a thermal phenomenon). This causes dew on leaves and possible dripping. Condensation on the stones of the walls and in the stony ground cover may also help to re-wet the soil.

- Interception of mist droplets by foliage (a mechanical phenomenon). The larger the droplets (fog) and the stronger the wind the more intense the phenomenon.

- Direct absorption by leaf stomata at low water potential of water vapour in the air when this is close to saturation.

In the light of the scale of the rainfall shortage, non-rainfall precipitation may play a non-negligible role in the survival of coffee-trees especially as late-afternoon mists are frequent. However, this is not sufficient for satisfactory vegetative growth, as was seen in 1991.

The two simple devices below will be installed to show whether the first two phenomena exist at the site and at what time of year:

- a pan containing a 30-cm bed of stones incorporated in a terrace. This will show if the condensation on the stones (non-porous) is sufficient to produce flow at the bottom of the pan. The pan will also be used to assess the depth of water intercepted by stone cover during rainfall;

- a recipient placed below the foliage to collect and concentrate dripping.

Direct absorption of water vapour by leaves is more difficult to demonstrate and quantify. The variation in trunk diameter during the night described in Chapter 3.5 appears to show this. A method based on use of a pressure chamber has been envisaged.

3.3 Rooting

It can be seen that the main roots run horizontally in old, uprooted stumps and there is no large vertical root. The most marked feature in the soil are these lateral roots at a depth of 20-24 cm and they go well beyond the vertical boundary of the branches.

Abundant small roots with rootlets grow upwards below the stone cover (Figure 1). At a depth, there are many small filamentous roots, even in the stony areas (scree) and the horizons whitened by limestone deposits. The terrace volume is probably explored.

Soil management at the foot of the trees prevents the development of large, shallow (10-15 cm) roots.

Termites have been noted and sometimes attack old plants.

3.4 Water characteristics of the soil

. Infiltration rate

Application of 40 l of water in an infiltration basin 80 cm in diameter (0.5 m^2) infiltrated in 32 min, i.e. 150 mm/h. Soil permeability is overestimated without a guard ring. Lateral diffusion is not more than 10 cm and can be situated at about 120 mm/h.

Permeability thus seems to be high in soil containing about 50% clay. This feature is explained by its excellent structure (good grainy structure), the presence of limestone and organic matter giving it good structural stability.

. Retention after free drainage for 24 hours

Over half of the watêr added (23 l) was retained in the first 20 cm of the soil. Moisture by weight in the fine soil only increased from 12.6 to 27.6%. This indicates retention of 143 mm per metre for the soil as a whole (20% stones).

At a depth of between 20 and 40 cm, the increase is only 63 mm/m. The fine soil (30% stones) was more moist before the experiment (15.7% of terrace bare soil with crops) and did not appear to have been fully re-wetted (22.1%).

The increase in moisture was not perceptible at a depth of over 60 cm. There did not appear to have been any rapid gravity flow (in fissures or macropores) at a depth.

Laboratory analysis will show the characteristic humidity levels. It already seems that the fine soil has a high retention capacity. However, frequent high stone contents reduce the useful storage capacity. These stones have low porosity (density 2.7) and retained only 2.4 % moisture when dipped in water and drained.

Conclusion

A 50-litre watering on an area 1 m in diameter will generally be retained by the soil within rooting range and without percolation loss.

3.5 Drought resistance

. The 1991 drought

There is a considerable shortage of rainfall. According to farmers, the only large rainfall was in April, enabling them to water (recharging the useful soil reserves). From 20.08 to 10.12, there were only four small occurrences of rainfall totalling 32 mm, whereas normal August and September rainfall totals about 300 mm.

The coffee-trees nevertheless fruited satisfactorily, revealing high resistance to drought. Irrigation does not seem to be indispensable for ensuring completion of growth and berry maturation, even in very dry years.

However, hardly any new leaves formed after the end of August. This halt in growth is shown in Figure 2 by the failure of stems to grow from August to November. This is in agreement with D. Kumar (Kenya Coffee, 1979) who noted that water stress affected growth more than it affected photosynthesis.

The wood formed in 1991 is very short and has few nodes. Its fruit-bearing potential is probably limited. Drought risks causing a decrease in production potential during the two subsequent years, unless there is a compensation mechanism.

. Variations in stem girth

The "PEPISTA" measurement system installed by BAFY on four coffee-trees has provided extremely interesting information, as can be illustrated by two features:

It can be seen in Figure 3 that application of 50 litres of water to to tree 2 was followed immediately by increased stem diameter (approx. 0.3 mm in 24 hours). The same phenomenon was observed in the three other plants after the small 6 mm rainfall of 03.10.91. It also appeared to benefit the tree watered the previous day. This rapid reaction is caused by the rehydration of stem tissues. Drought causes the tissues to contract again a few days later. Figure 2 shows that the phenomenon is very gradual; it took over five weeks to return to the stem diameters of before the rainfall. Coffee-trees appear to economise their water.

On the scale of a day (Figure 4), solar radiation causes contraction (dessication) which is most marked between 1200 and 1400 hours. The stems swell again rapidly in the evening in relation to the rise in atmospheric humidity and the formation of mist. The clearing of the mist and the arrival of drier air from 2200 hours onwards immediately caused slight stem contraction. In these coffee-plants growing under conditions of severe water stress (dry soil), there appears to be a balance at night between atmospheric humidity and tissue turgor. This leads to supposing that the coffee-trees absorb atmospheric moisture through leaf stomata.

3.6 Flowering and fruiting

The main harvest is in November following flowering triggered by the first significant rainfall in about March. Fruit formation seems to be rapid (7-8 months). Light rainfall (10 mm or perhaps less) is enough to cause flowering. If such rainfall is isolated, as often seems to be the case, it cannot re-moisten the soil and enable vegetative growth to re-start (the leaves are defoliated to varying extents). In this case, if the subsequent rain is long in coming, the flowering success rate may well be low.

It would seem at first sight that any watering during this critical phase must necessarily be beneficial, firstly by enhancing fruit setting and secondly by stimulating the re-starting of vegetation (growth of new leaves); the trees will then be able to profit from the more substantial rainfall which normally occurs in April or May.

It is noted that many of the coffee-trees on the terraces close to the trial zone bore young fruits (3 to 8 mm) in mid-December, which probably grew from August flowering, which had little chance of reaching maturity in the middle of the dry season. Successful first flowering will reduce the occurrence of such delayed fruiting which is harmful for production.

The observations that are to be made in 1992 will provide further details on this phenological data.

3.7 Water balances and requirements

Because of the spacing and limited development of the coffee-trees, the plantations in the Yemen have smaller water requirements than those of plantations with full foliage cover (0.7 to 0.8 PET required in E. Africa). A preliminary calculation made by multiplying these requirements by the ground coverage rate (0.36) gives a cultural coefficient of about 0.25, which seems much lower than reality (annual requirements of 250 to 300 mm).

Other values were tested by simulating the water balance (BIPODE program). With a coefficient of 0.5 in full vegetation, the results agree fairly well with the 1991 observations. This program can thus be set progressively and empirically. It is remineded that it aims above all at facilitating the analysis and comparison of varied agro-climatic condtions (and is not intended for accurate measurement of water flows).

IRAT will provide another version of the BIPODE program which separates soil evaporation and transpiration. A bibliographical study reviewing the water requirements of low density bush plantations would be useful.

IV - TRIAL PROCEDURE

4.1 Purpose

The aim is to test the effectiveness on coffee-tree production of supplemental irrigation applied in the form of small local waterings (50 litres per tree) from cisterns, taking into account the limited storage capacity (50, 100 and 150 litres per tree), in comparison with non-watered control plants.

4.2 Watering dates and conditions

. At flowering

* The purpose is to ensure successful setting and to trigger the re-starting of vegetative growth.

* No watering if the rain has deeply re-moistened the soil.

* If it has not rained by 10th March, half of the replicates will be watered to trigger flowering.

The table below defines the storage capacity of the four treatments (the dates are provided as an example):

Treatment	Storage capacity (l)	Watering (l)		
		10.03	25.03	10.04
T3	150	50	50	50
T2	100	50	50	0
T1	50	50	0	0
T0	0	0	0	0

. <u>During vegetation</u> (May to July)

* To handle one or more short dry periods in order to enhance fruit growth and prevent shedding.

* If the cisterns are not empty (if there has been runoff since the previous use)

* Not after 1 August (water stored for the following year).

Watering will thus depend to a great extent on the year's rainfall.

4.3 <u>Field treatment</u>

It is not possible to work on homogeneous groups of coffee-trees (micro-plots) because of the small size and the heterogeneity of the terraces. The treatments will thus be applied to one plant at a time We assume that applying 50 litres of water to the base of a tree will benefit essentially the tree in question.

Figure 5 shows the positioning of the 24 coffee-trees (4 treatments x 6 replicates) chosen in the Beni Ismail experimental zone.

4.4 Monitoring methods

The impact of the supplemental watering will be observed by individual monitoring of coffee-trees, consisting mainly of:

- measurements of vegetative growth: appearance or shedding of leaves (monthly), length and number of internodes formed during the year;

- measurement of variations in the diameter of a main stem in four plants using the "PEPISTA-INRA" system;

- monitoring fruit growth: the number of remaining berries and the size at several nodes;

- harvesting ripe fruits.

Leaf water potential and soil moisture will be measured to assess the intensity of water stress.

The mission was an opportunity to finalise various procedures and practical methods with Mr Neuvy.

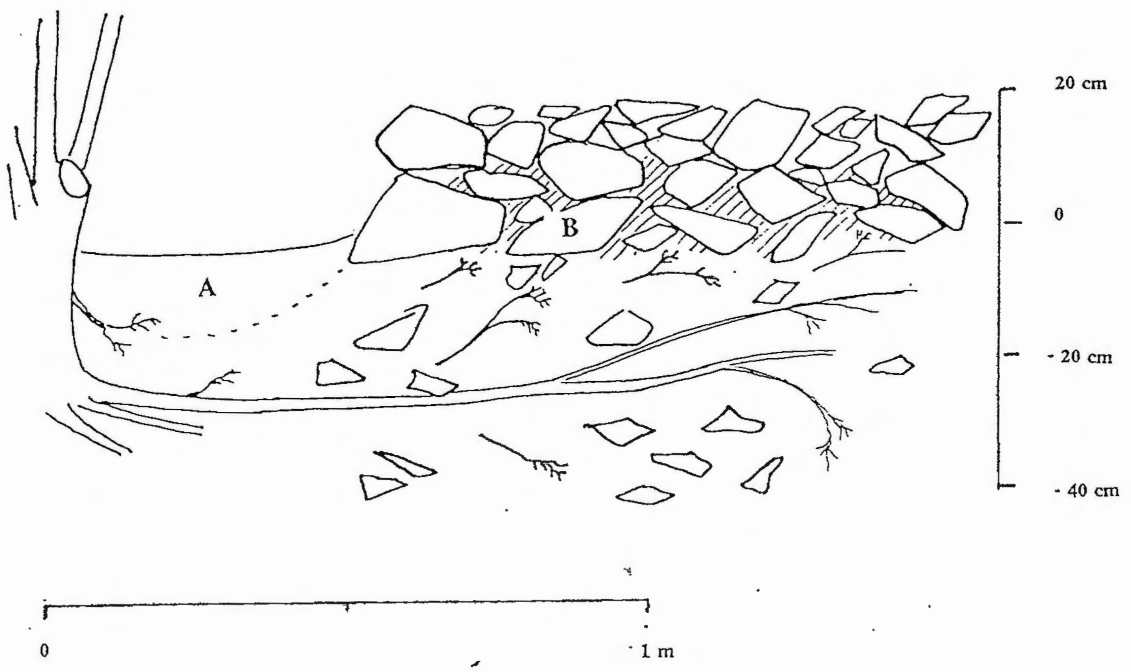


FIGURE 1: POSITION OF LATERAL ROOTS UNDER STONY COVER

A: Cultivated zone at the base of the tree
B: Stony cover, partly filled by soil

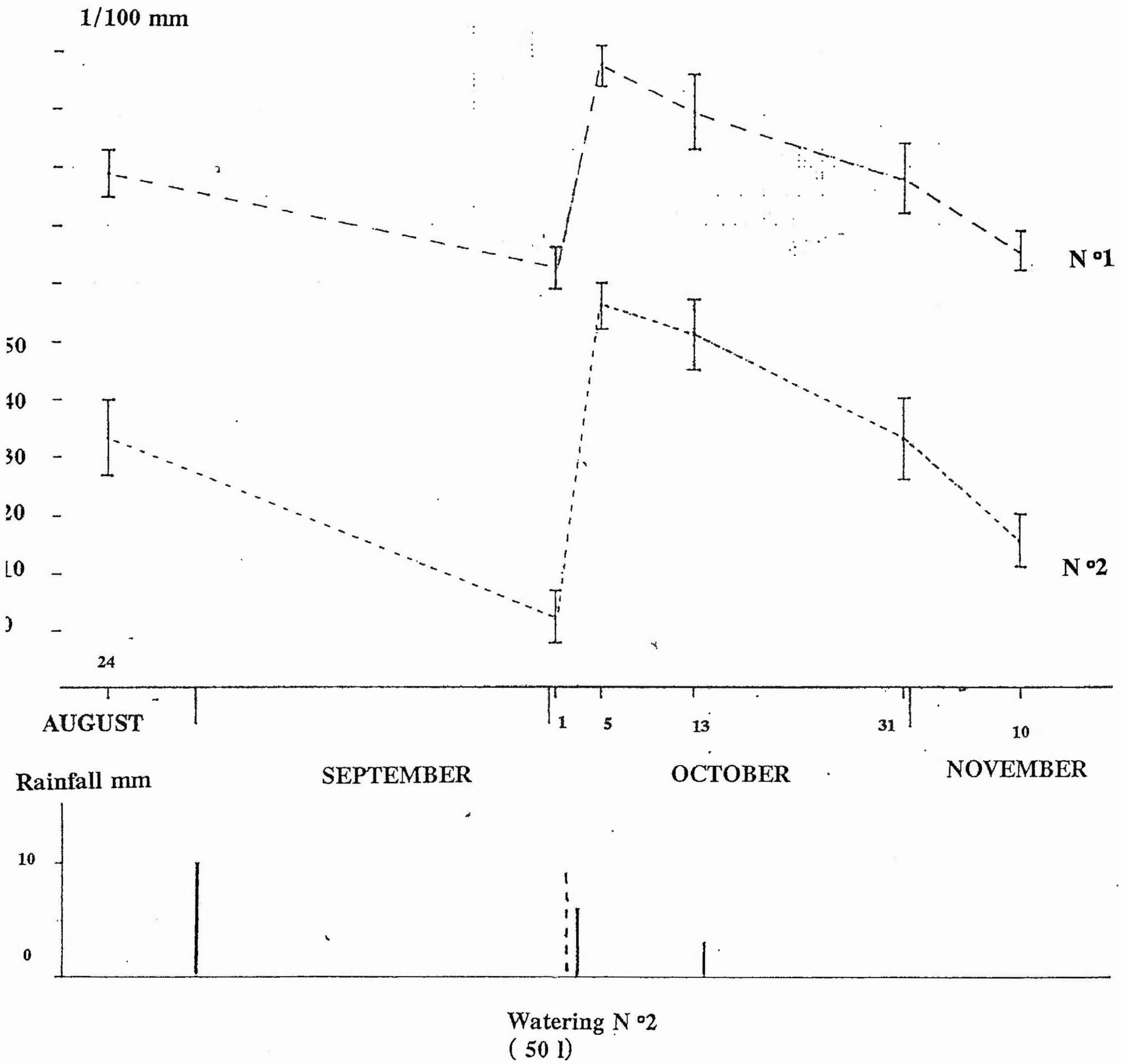


FIGURE 2: VARIATION IN THE STEM DIAMETER OF 2 COFFEE-TREES; DAILY AMPLITUDE (I), IMPACT OF RAINFALL AND WATERING (COFFEE-TREE No. 2); PERSISTENCE OF THE EFFECT.

Source: BAFY

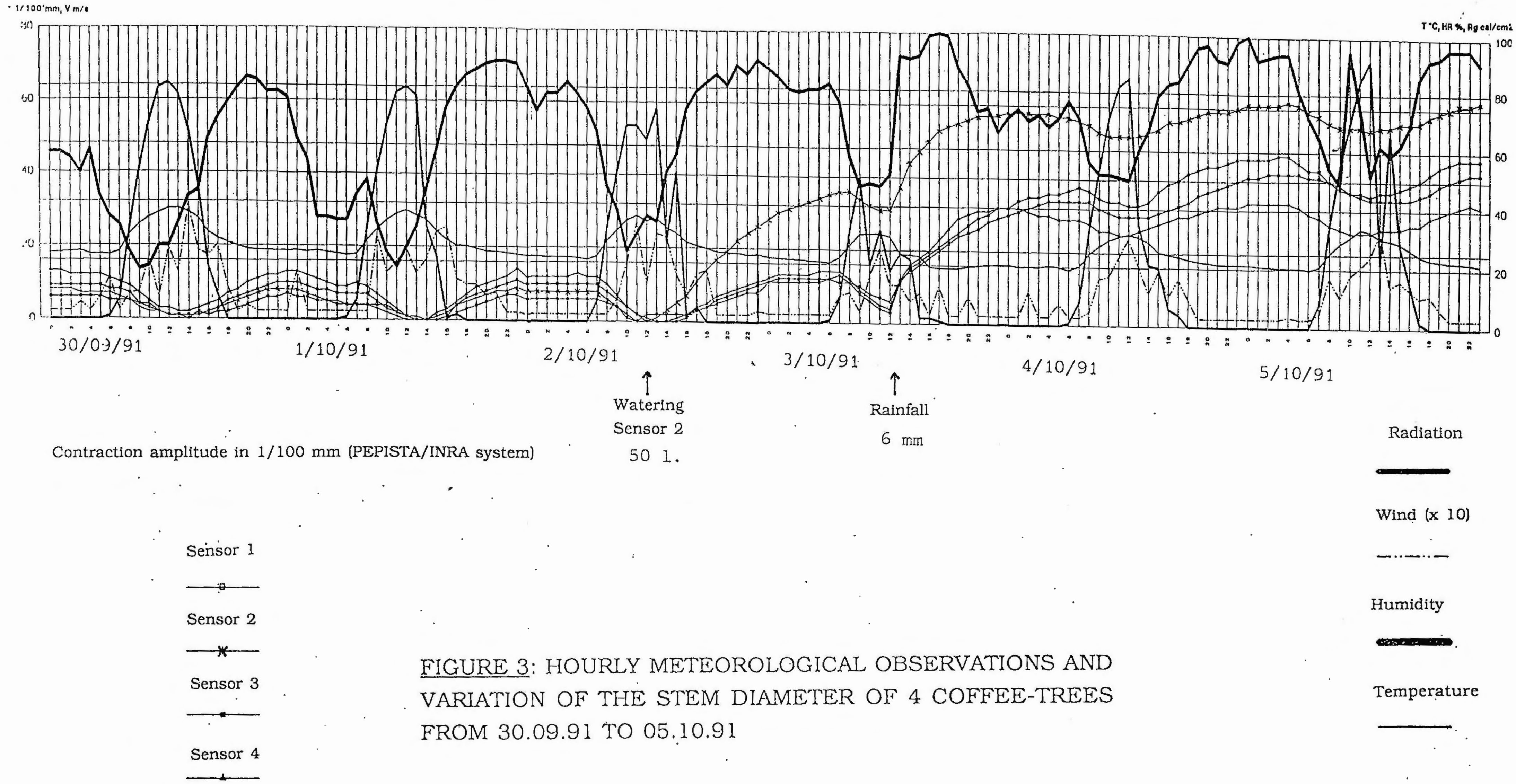
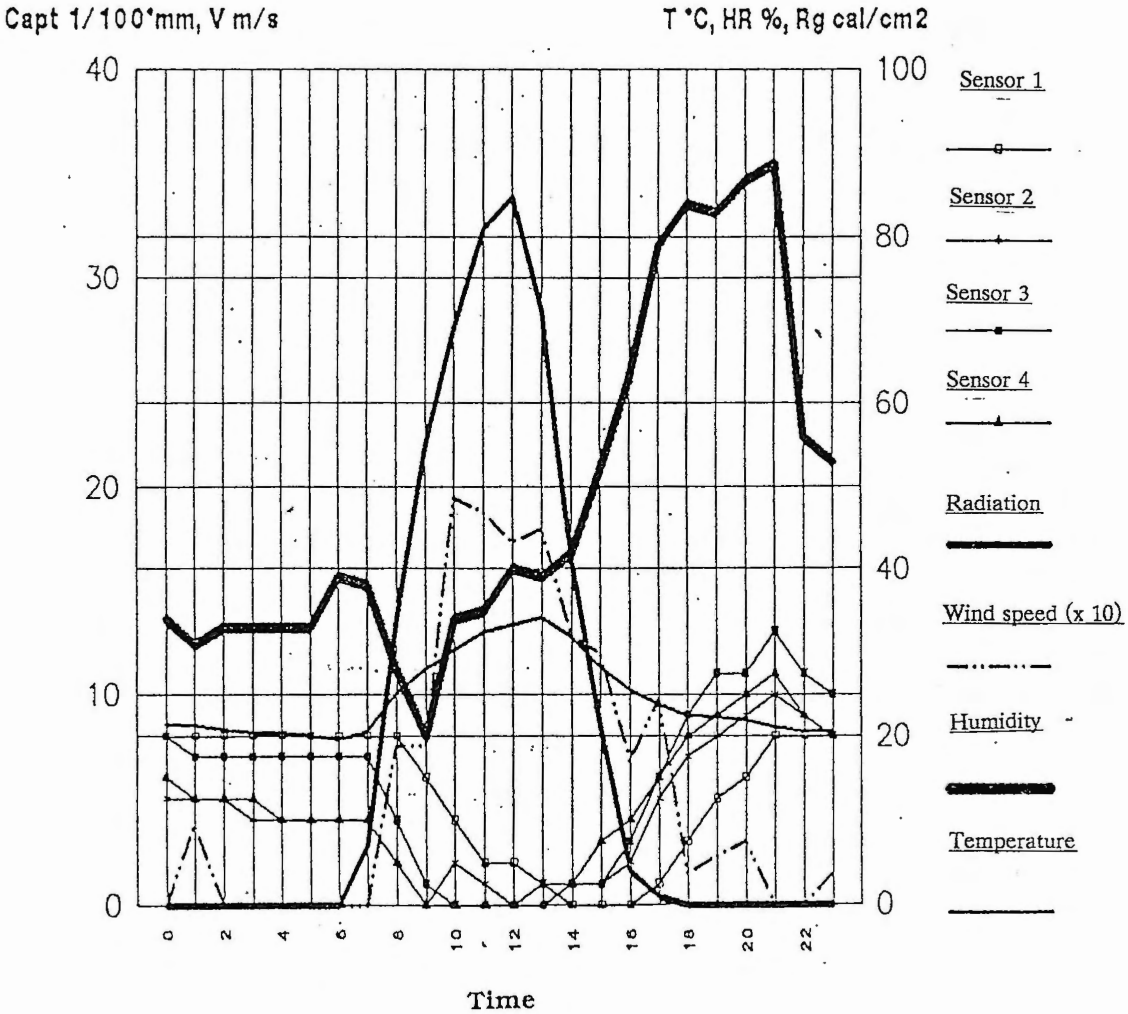


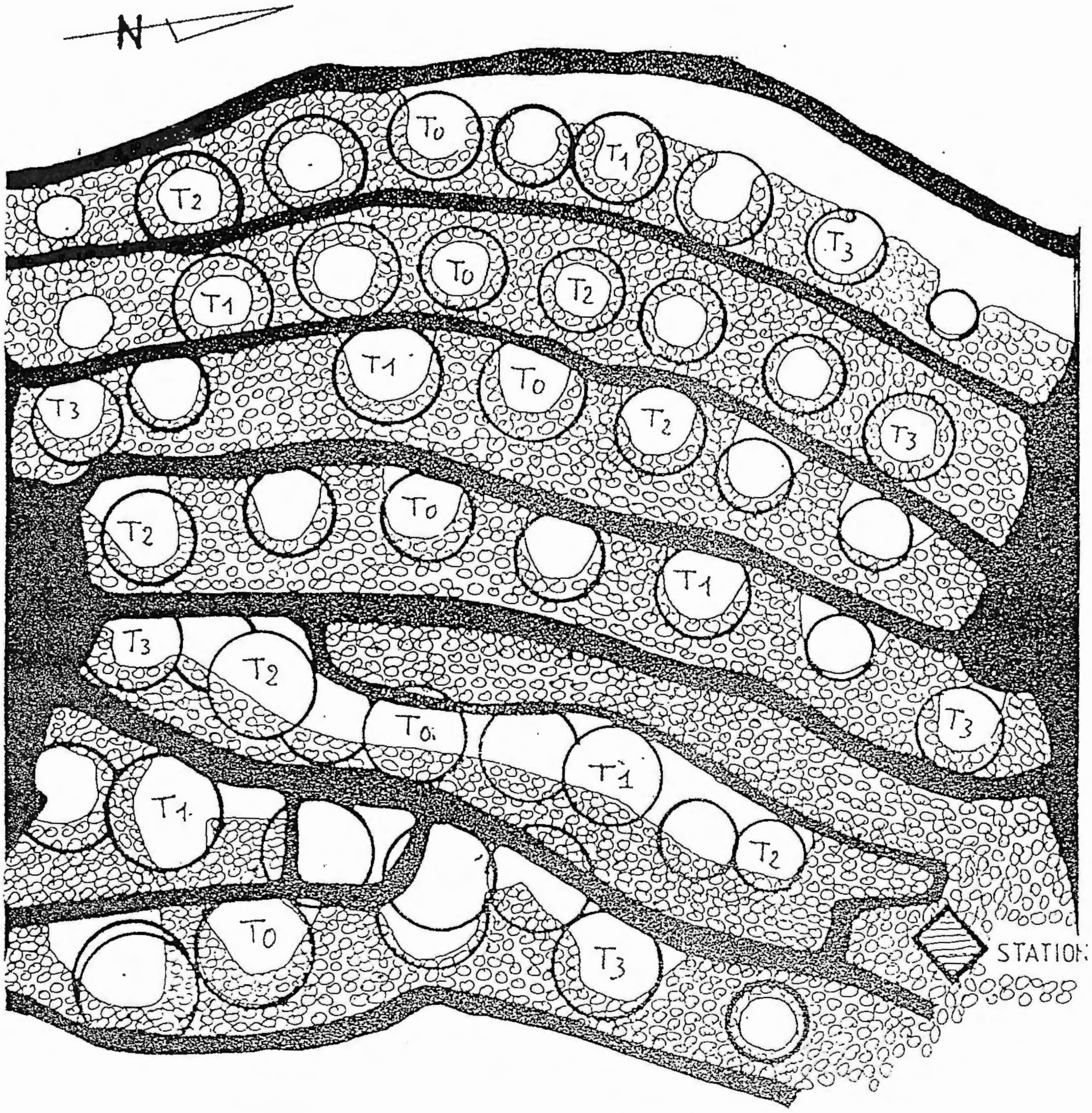
FIGURE 3: HOURLY METEOROLOGICAL OBSERVATIONS AND VARIATION OF THE STEM DIAMETER OF 4 COFFEE-TREES FROM 30.09.91 TO 05.10.91

FIGURE 4: SYNOPTIC RECORD 6.2 (2nd third of October)
'Gaadi' Arabica, Alt. 1950 m
Typical day: 16/10/91



Contraction amplitude, 1/100 mm (PEPISTA/INRA system)
10-day PET: 44 mm

* Daily averages:
Rtot cal/cm2, WS 0.6 m/s
RH 48%, T 26.9°C, PET 4.5 mm



parent rock

walls

stony cover

bare soil

coffee-trees

Scale : 1/200 °

T0 control

T1, 2, 3 supplemental irrigation

FIGURE 5 Plan of the Beni Ismail plot

BAFY